Retrieving Cloud Optical Properties Over Snow and Ice Covered Surfaces

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Photos courtesy of Madeline Minnis & ARM

Retrieving Cloud Properties Over Snow Using Reflected Sunlight

- Ice – cloud albedo feedback important climate parameter
  - need to know long-term change in polar cloud properties
  - variability in cloud optical depth (COD) & liquid/ice water path greatest among observations => large uncertainties
  - seek best techniques available for current/future satellite imagers
- Snow highly reflective at shorter wavelengths
  - low cloud/snow contrast: COD very sensitive to sfc albedo uncertainty
- Snow darker at longer wavelengths (> 1 μm)
  - much better cloud/snow contrast
    - *surface albedo highly variable with snow cover*
  - clouds also highly absorbing => *OD limitations*
- What is best approach?
  - clouds over snow retrieval has not yet been studied systematically

Objective

• Determine optimal channels for retrieving cloud optical depth (COD) τ, effective particle size Re, and liquid or ice water path LWP/IWP using reflected solar spectral radiances measured by satellites

Approach

• Examine theoretical / empirical potential for several wavelengths used by operational & research satellite imagers

- Assumes retrieval of Re using 3.8-µm radiances
- Subject wavelength used for retrieving τ
- LWP = 0.67 τ Re

• Perform retrievals using various wavelengths

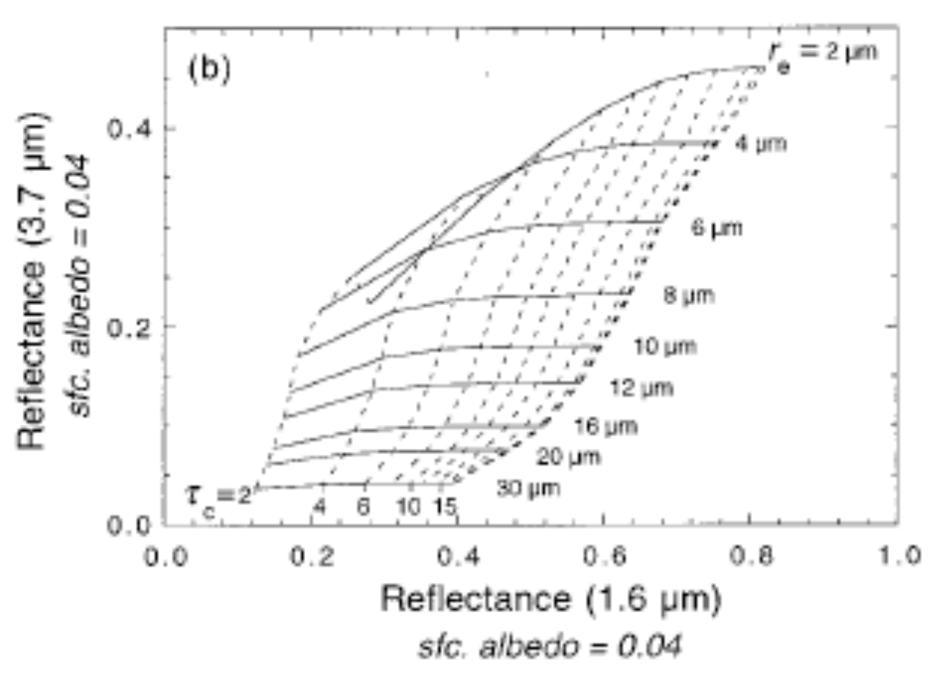
- Assumes retrieval of Re using 3.8-µm radiances
- Subject wavelength used for retrieving τ

• Compare LWP with surface-based MWR retrievals of LWP

Background

- Retrieval of OD using visible wavelengths yields large cloud optical depths over sea ice and snow (e.g., ISCCP, *Rossow & Schiffer 1999*)

- *Platnick et al. (2001)* pioneered use of near-infrared absorbing channel, 1.6 µm, to derive τ over snow yielding more realistic values



Variation of 1.6 & 3.7-µm reflectance with τ and Re

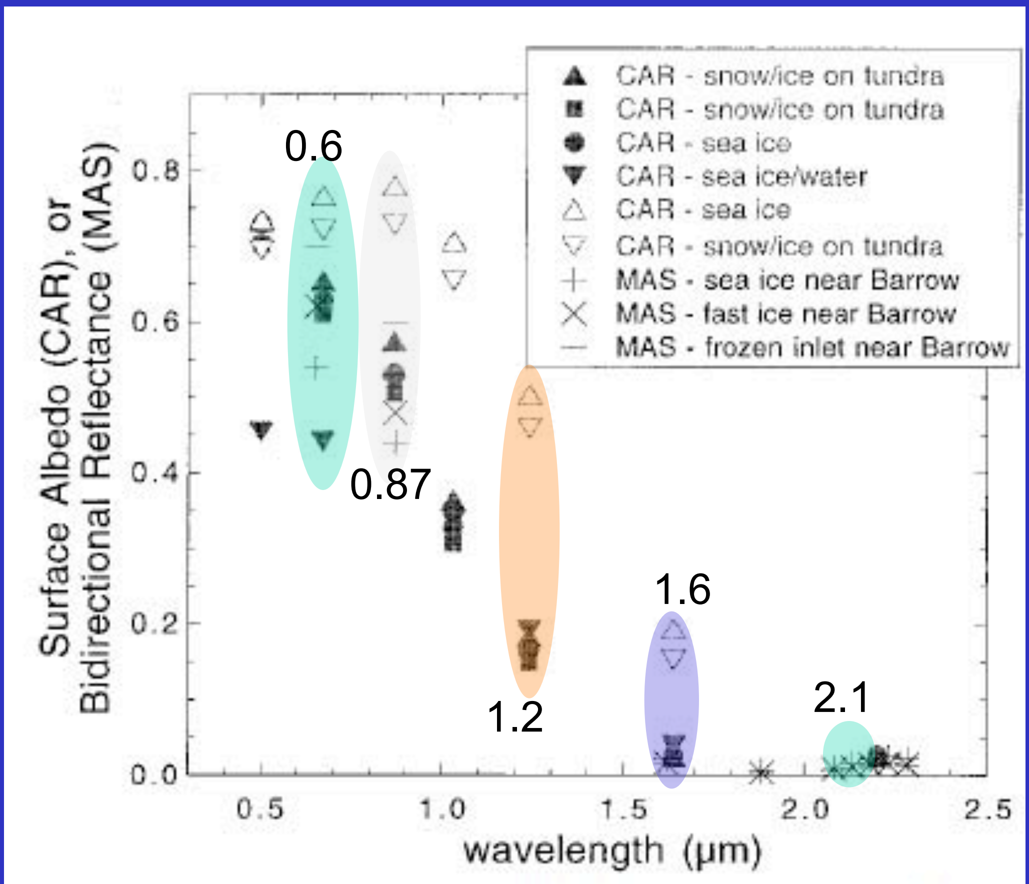
- 1.6-µm snow albedo ~0.05
- good separation of reflectance pairs for given τ and r_e
- large range of 1.6 µm reflectance

=> good for cloud retrieval

From Platnick et al., JGR, 01

Background

- Snow/ice albedo decreases at longer wavelengths providing contrast with clouds



From Platnick et al., JGR, 01

Sea ice & spectral snow albedos measured by airborne radiometers

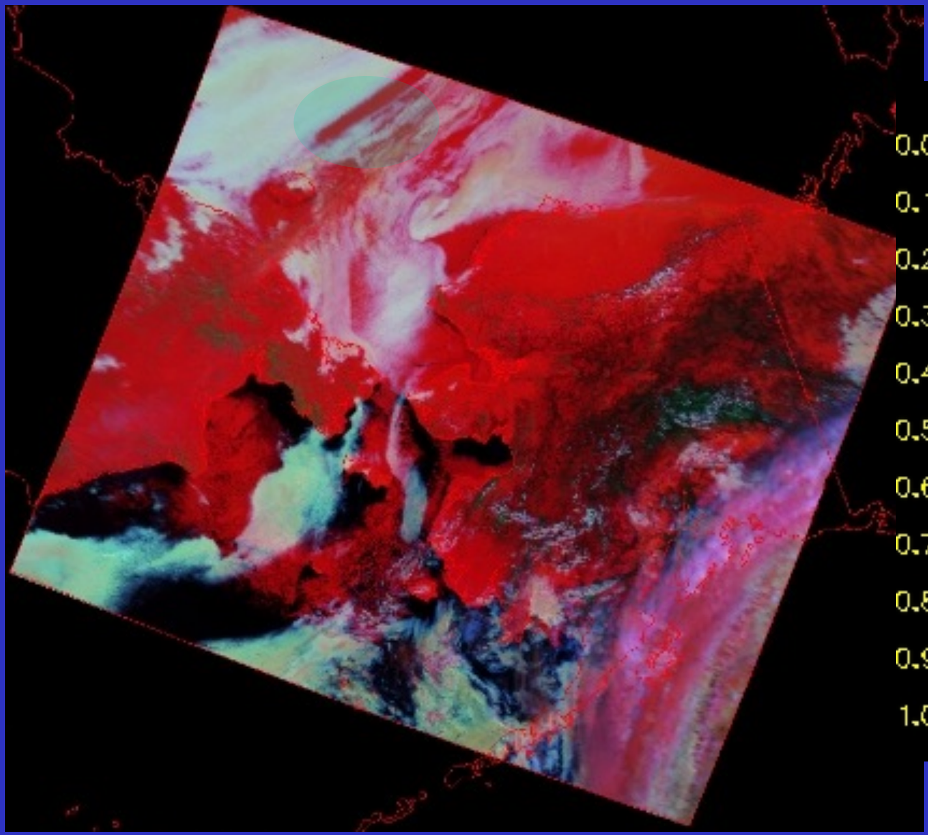
- large variability in snow albedo
- lowest albedo for λ > 2 μm
  - give best contrast
  - not as variable
- 1.6-μm snow albedo ~0.05

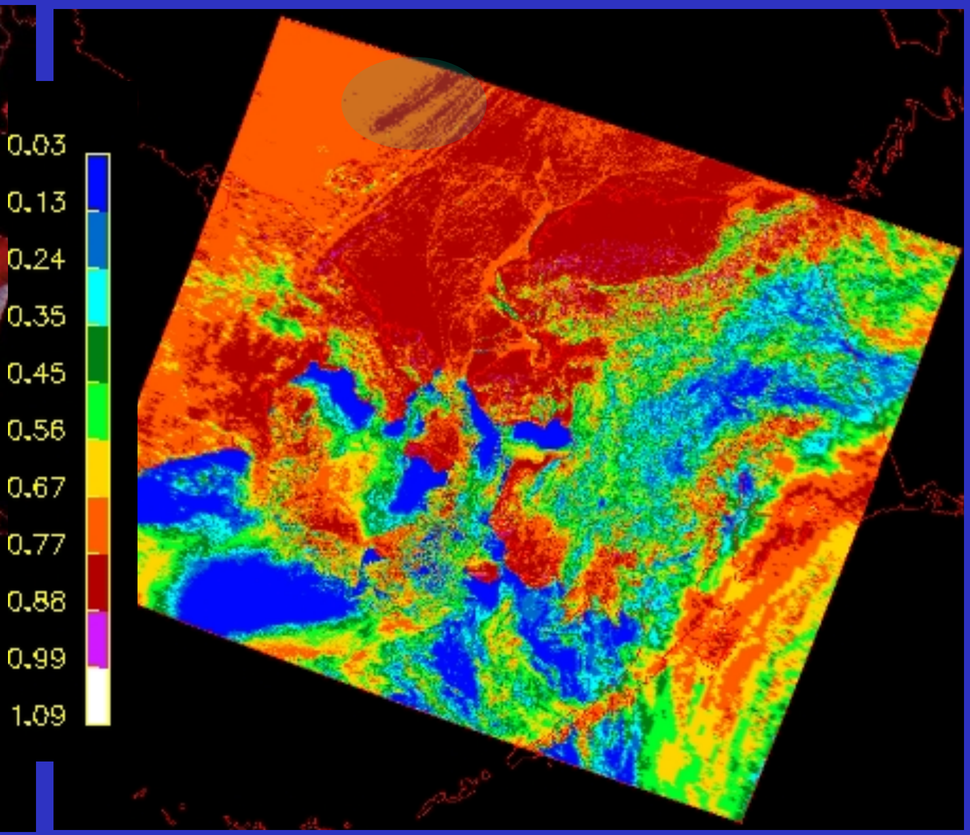
  => good for cloud retrieval over snow

Visible Channel Reflectance

Terra MODIS, 2200 UTC, 3 May 2006

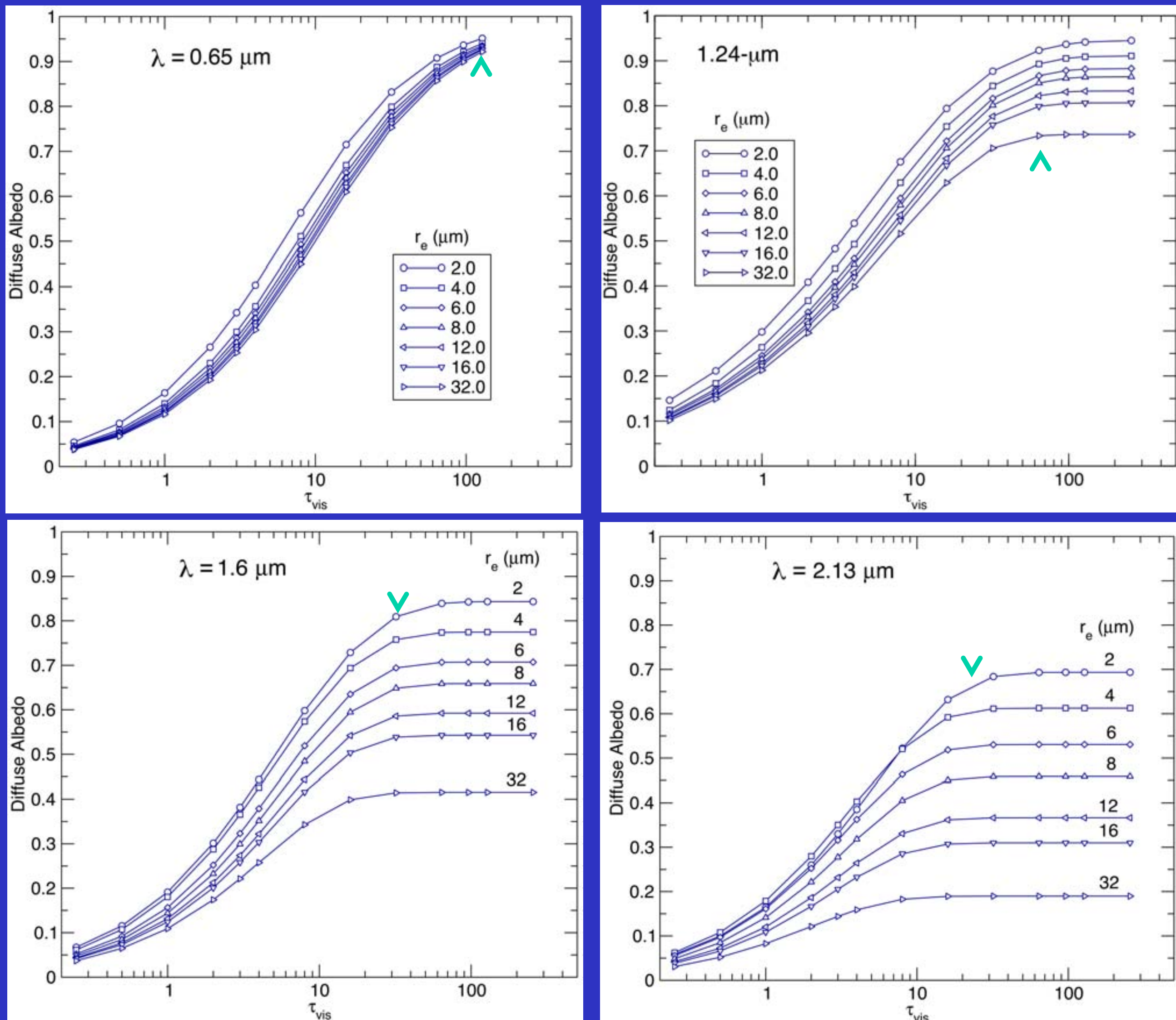
0.62-μm Reflectance





- Greater reflectance of surface becomes problematic for cloud retrievals

Diffuse Liquid Cloud Albedos from Adding-Doubling Computations



Cloud model

- modified Γ dist
- σ = 0.10
- Mie scattering
- sfc albedo = 0

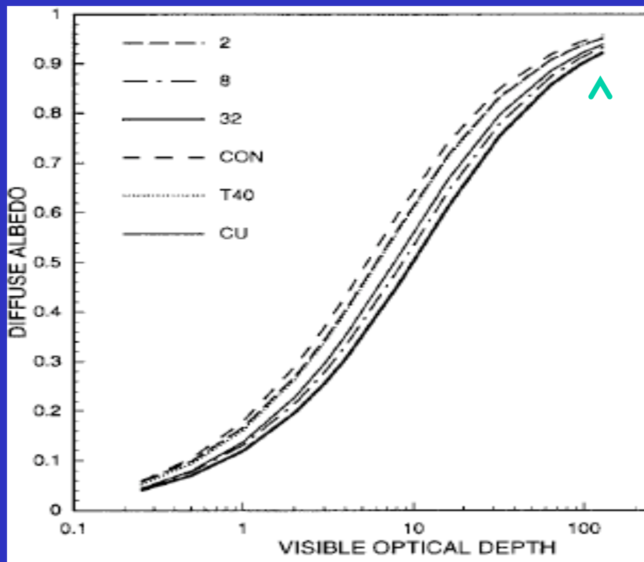
Minnis et al. JAS, 1998

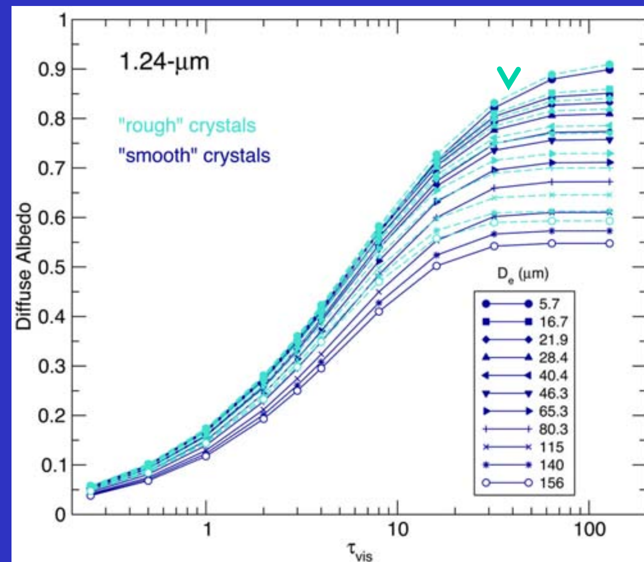
λ (µm)	τ Limits
0.65	> 128
1.24	64 - 96
1.62	32 - 40
2.13	18 - 30

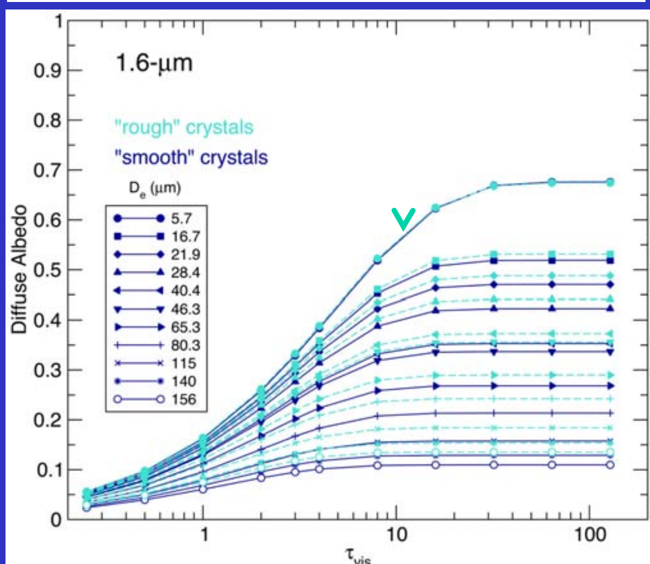
Actual limits depend on viewing & illumination angles & sfc albedo

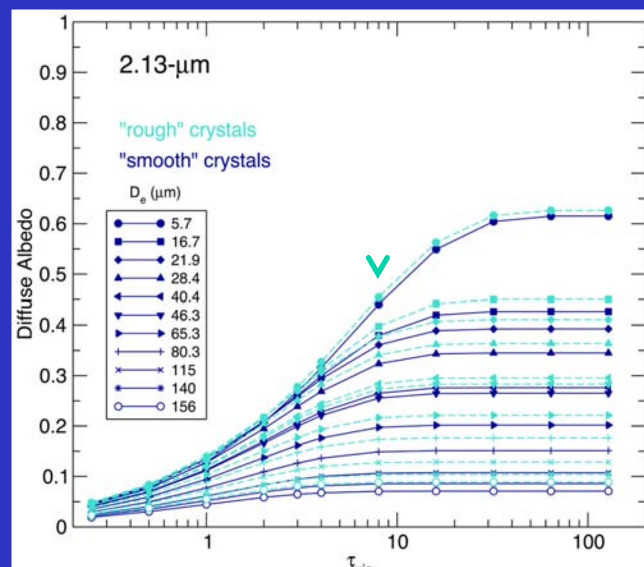
1.24 µm channel has promise for getting most of full range of τ

Diffuse Ice Cloud Albedos from Adding-Doubling Computations









Ice model based on hex column dist

Minnis et al. JAS, 1998

λ (µm)	τ Limits
0.65	> 128
1.24	32 - 60
1.62	8 - 16
2.13	4 - 8

Actual limits depend on viewing & illumination angles & sfc albedo

1.24 µm channel has more promise for getting most of full range of τ

Average Clear Spectral Albedos Over Various Land Types Observed from CERES Ed2 Terra MODIS, 2000-2005

Surface type	0.65 μm	0.87 μm	1.6 μm	2.1 μm	1.2 μm
snow -free					
forest	0.134	0.244	0.206	0.133	0.231
grass	0.184	0.252	0.276	0.215	0.316
desert	0.272	0.330	0.382	0.324	0.368
coast	0.137	0.159	0.129	0.087	
ocean	0.075	0.042	0.021	0.016	0.033
Snow-covered					
forest	0.388	0.472	0.152	0.064	0.331
grass	0.595	0.654	0.172	0.071	0.322
desert	0.618	0.661	0.182	0.082	0.333
coast	0.553	0.626	0.158	0.060	
ocean	0.629	0.604	0.102	0.032	0.309
snow-ice	0.860	0.852	0.148	0.044	0.400

- 0.65 & 0.87 μm
  - snow much brighter than snow-free scenes
- 1.6 & 2.1 μm
  - *snow generally darker than snow-free (not ocean)*
- 1.24 μm
  - *snow albedos not much different from snow-free albedos over grass & desert*
  - *snow brighter over ocean and forest*

CERES Retrieval of Cloud OD, r_e, LWP/IWP Using MODIS Data

CERES = Clouds & the Earth's Radiant Energy System

- Different, but similar to MODIS cloud team retrievals
- Cloud detection
  - *Minnis et al. (TGRS, 2008)*
  - *Trepte (IEEE, 2003)*
- Cloud Retrieval *(Minnis et al., TGRS, 2011)*
  - Visible Infrared SW-infrared Split-window Technique (VISST)
    - *R_e from 3.8 μm, τ from 0.67 μm, T_c from 11 μm*
  - SW-infrared Infrared Near-infrared Technique (SINT)
    - *Same as VISST, except τ* ***from an NIR channel***
      - **** NIR = 1.24, 1.62, 2.13 μm***
  - Both require atmospheric corrections, sfc albedo, & BRDF

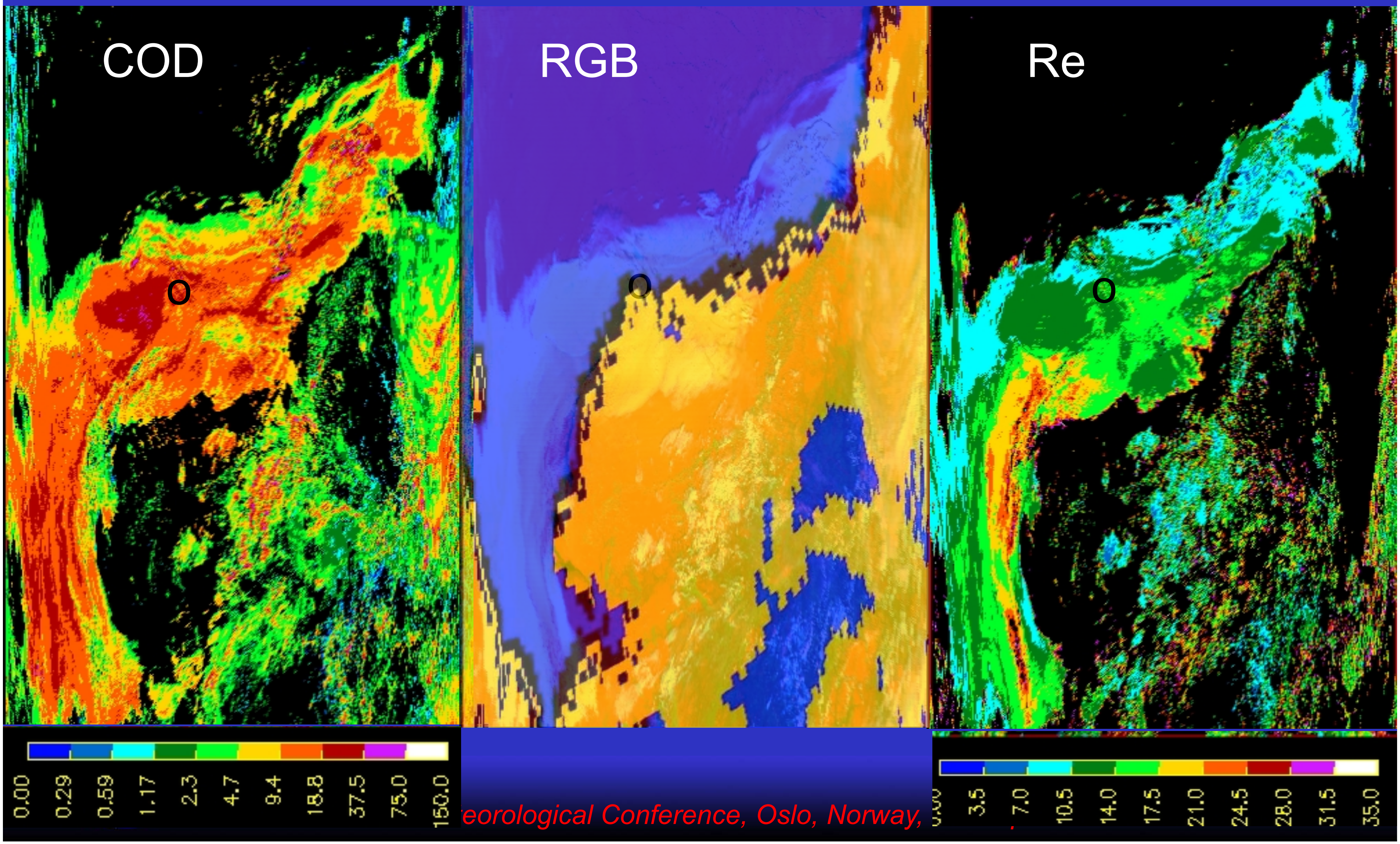
ARM NSA Validation Data, Barrow, AK, March – June 2007

- Cloud fraction CF from radar-lidar data
- Liquid water path (LWP) from µwave radiometer ($\underline{+}$20 gm^{-2})
- Re, COD derived by matching SW flux & LWP with RTM parameterization of Dong & Mace (2003) ($\underline{+}$11%)
- Hourly averages centered on MODIS time, CF =100%

- MODIS retrievals averaged over r = 20 km circle
- Liquid cloud fraction must exceed 50%
- Snow can be either from adjacent ocean, NSA land, or both

CERES Ed4 Cloud Retrievals, Terra, 22 UTC, 24 Apr 2007

	NSA	1.2 µm	1.6 µm
COD	20.7	18.8	16.3
Re (µm)	8.8	13.5	13.8
LWP (gm^{-2})	116	163	157

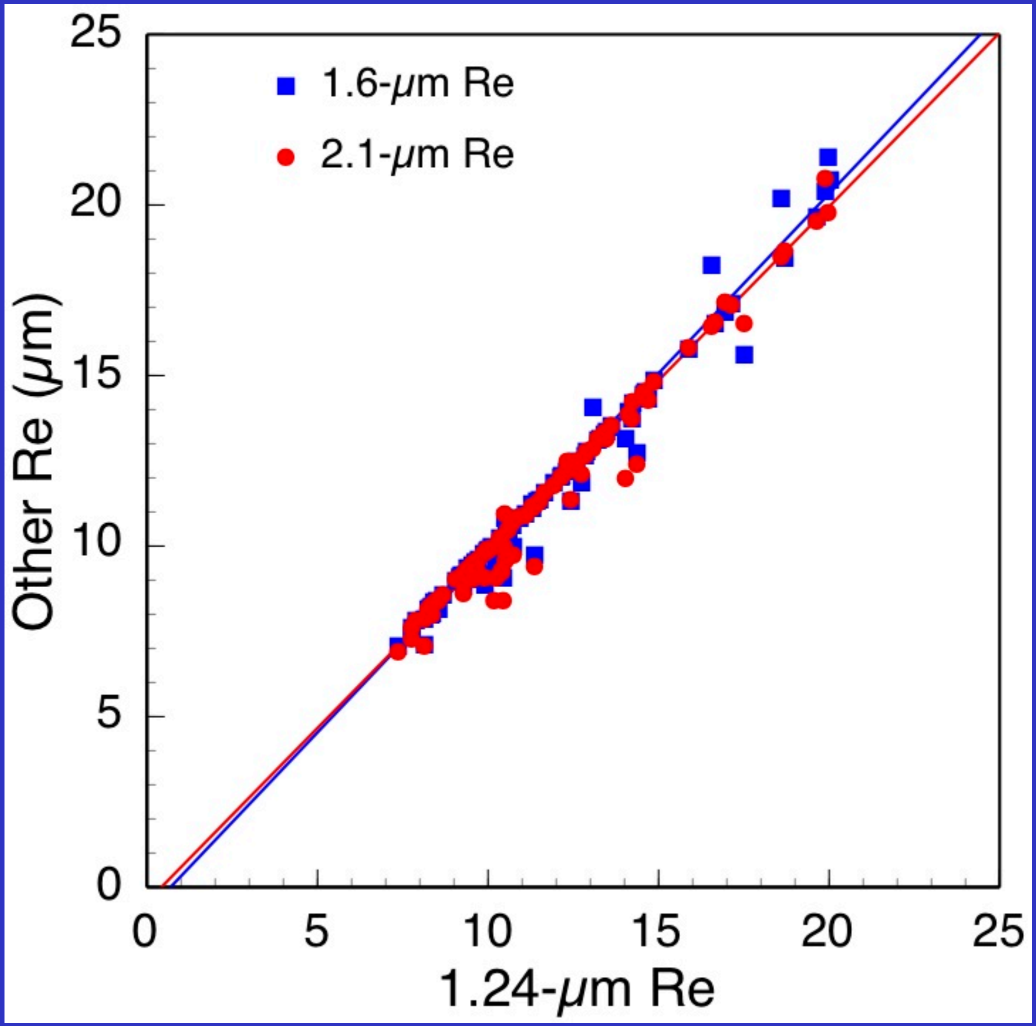


Re Retrievals Using Various Terra NIR Channels For COD

- Little to no variation in Re

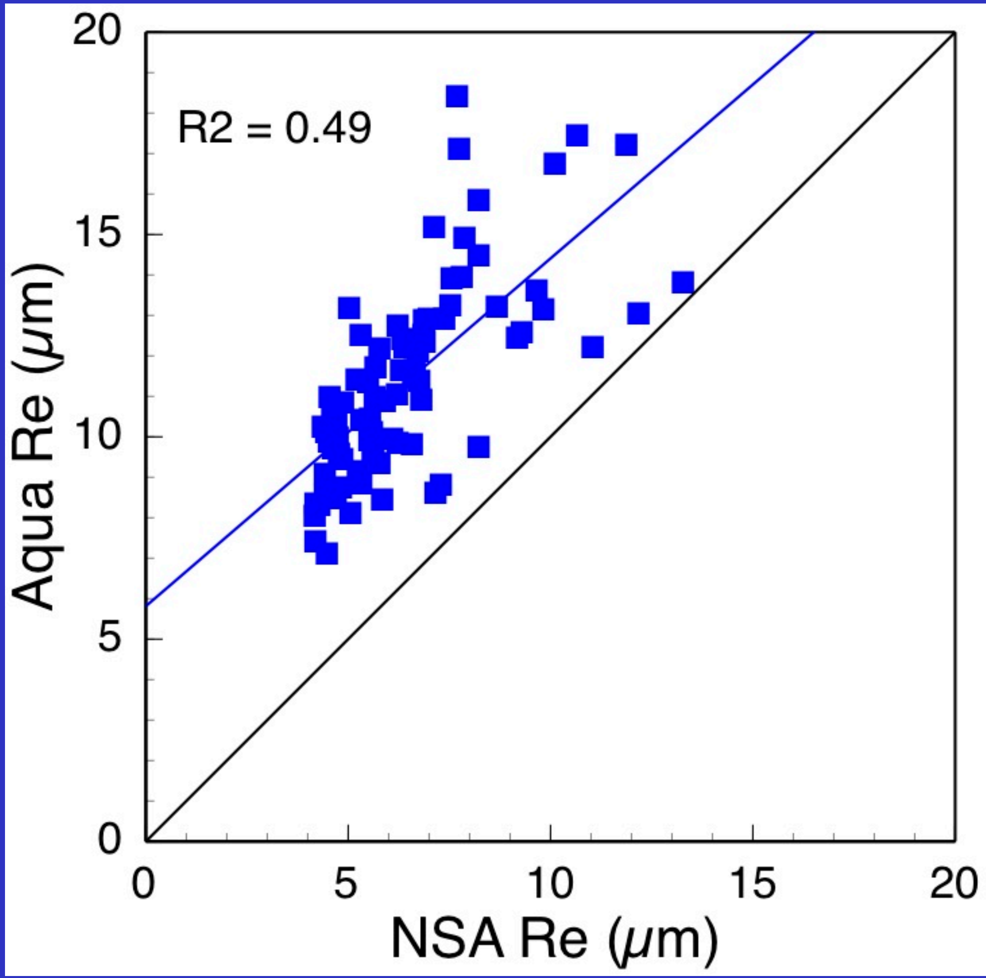
  => Re primarily relies on 3.7-µm radiances

- Expect greatest differences in COD



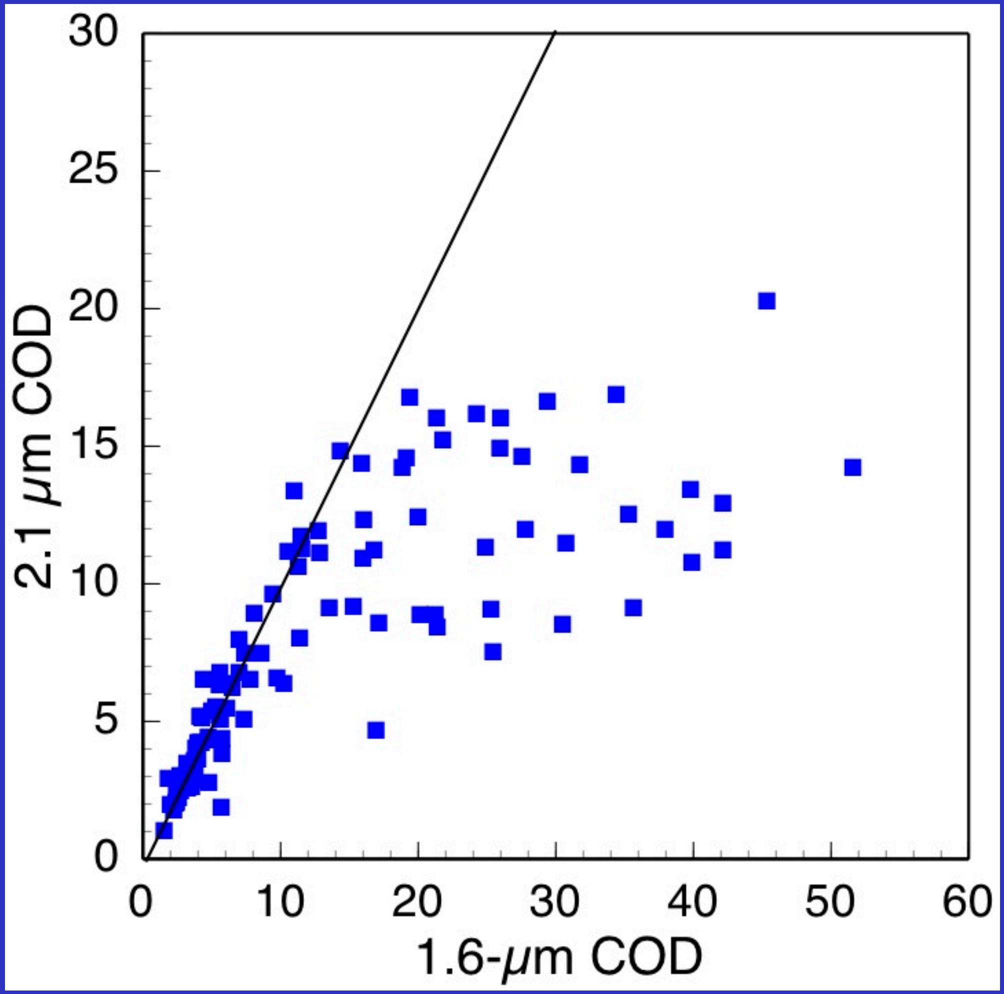
Aqua Re from COD(1.2 µm) vs. ARM NSA Re

- Reasonable correlation
- 4.9 ± 1.8 µm overestimate
  - *- unusually high*
- 3.7-µm top of cloud effect?
  - *- too large?*
  - *- comparable values from MYOD08 using 2.1 µm*
- underestimate from sfc?
  - *- not validated over snow*



Terra COD(2.1 µm) vs. COD(1.6 µm)

- Excellent agreement for COD < 8
  - *would be greater range for smaller Re*
  - *can replace 1.6 µm channel for small CODs*



Terra MODIS COD vs ARM NSA COD, CF > 50%

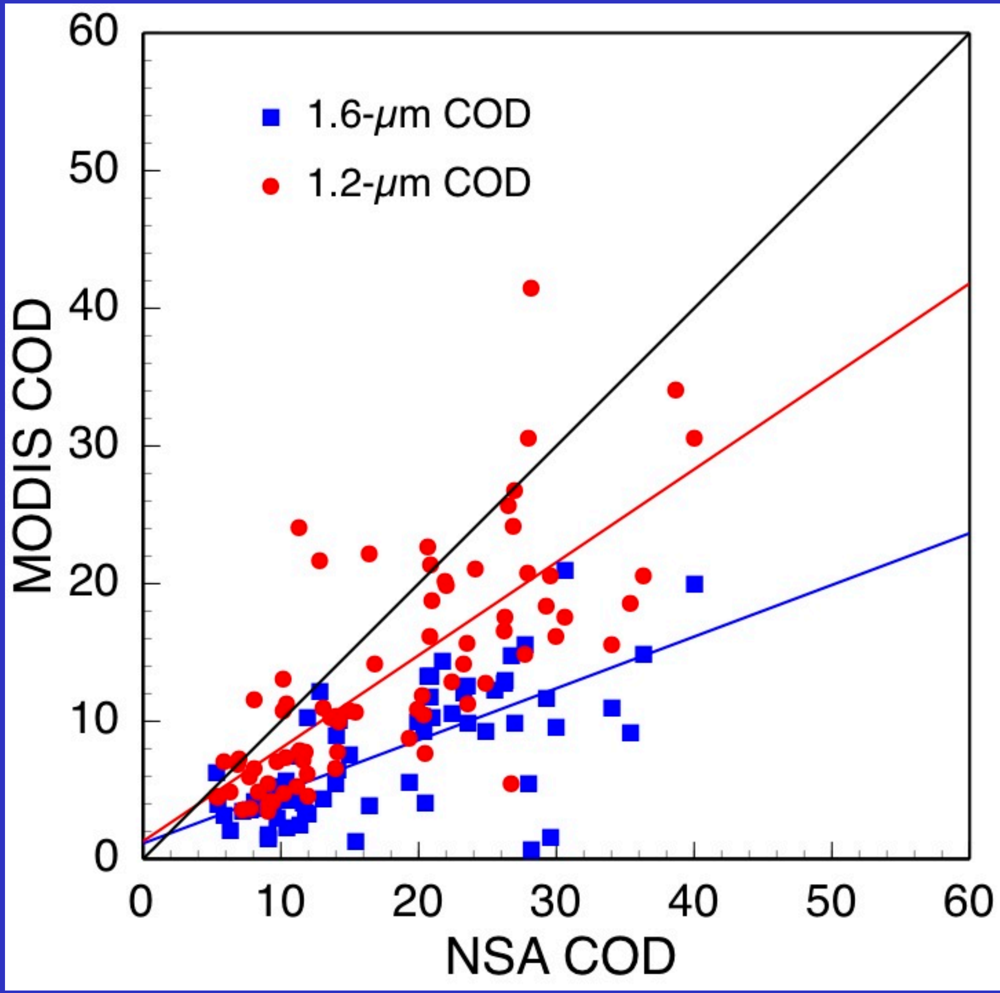
MODIS vs NSA

1.2 µm: $R^2 = 0.56$

Dif = -5.4

1.6 µm: $R^2 = 0.48$

Dif = -9.7



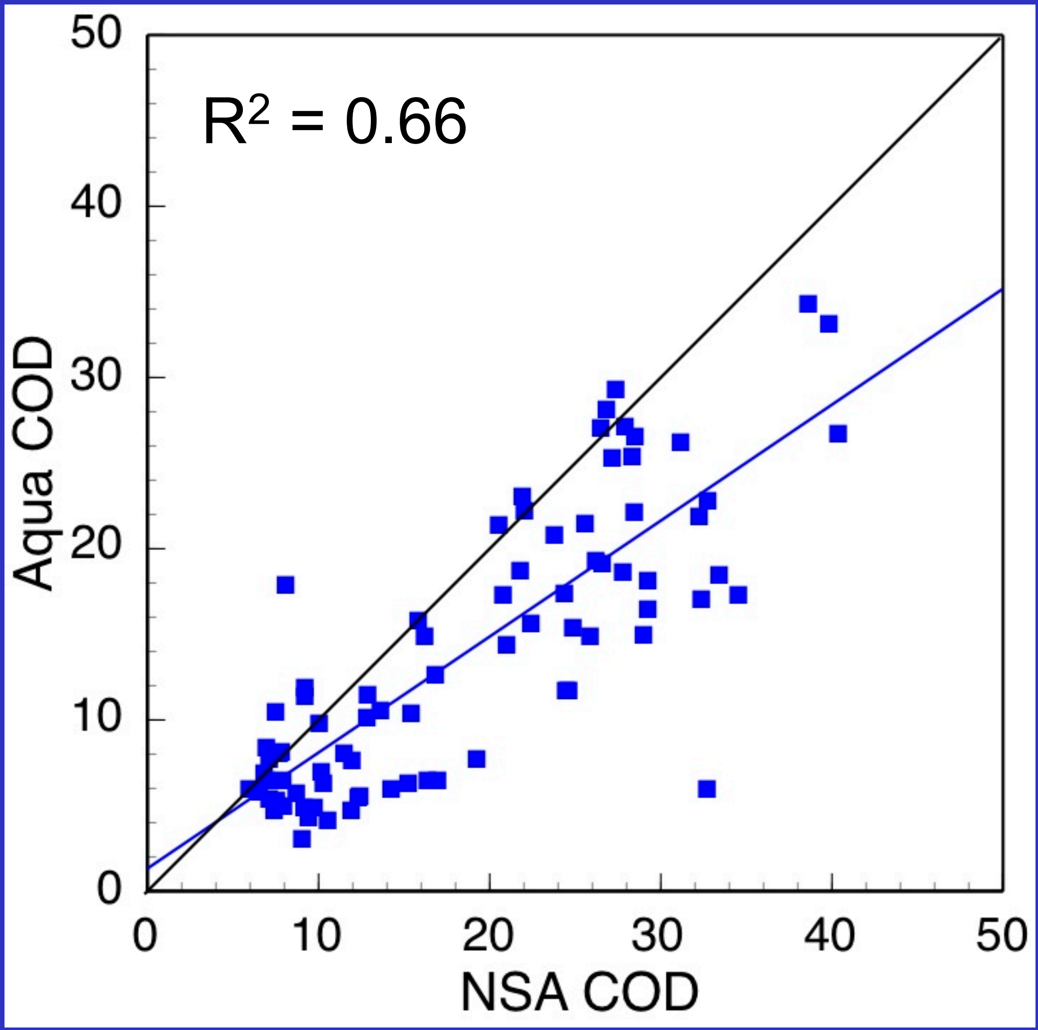
Aqua 1.2-µm COD vs ARM NSA COD, CF > 50%

MODIS - NSA

- ΔCOD = -4.7 ± 5.6

  = -25 ± 30%

- sensitivity of NSA and 1.24-µm COD to state of adjacent water and land

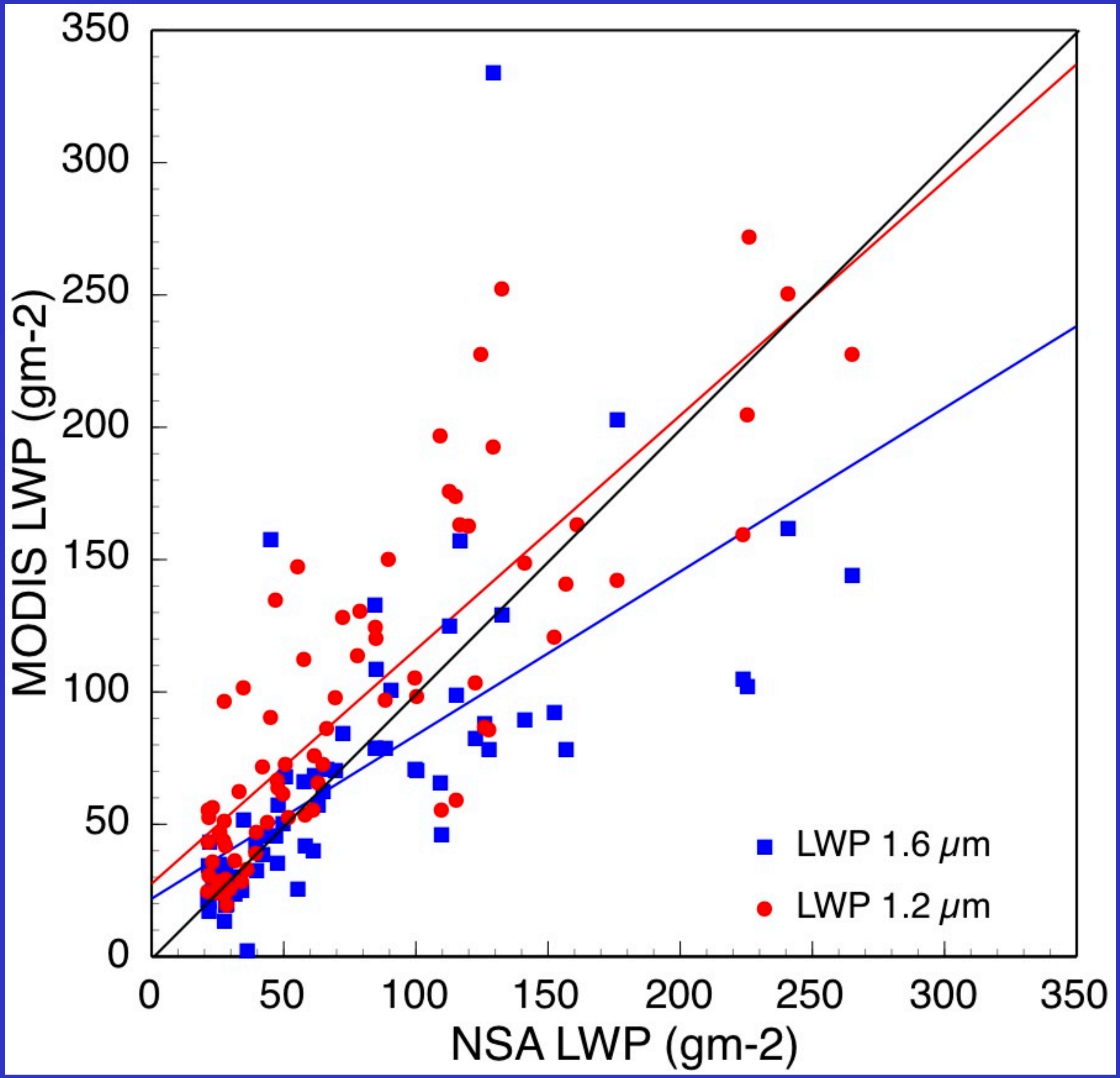


Terra CERES-MODIS LWP vs ARM NSA LWP

<u>Bias: MODIS – NSA</u>

1.2 µm: 20.1 gm^{-2}
(27%)

1.6 µm: -6.1 gm^{-2}
(-8.5%)



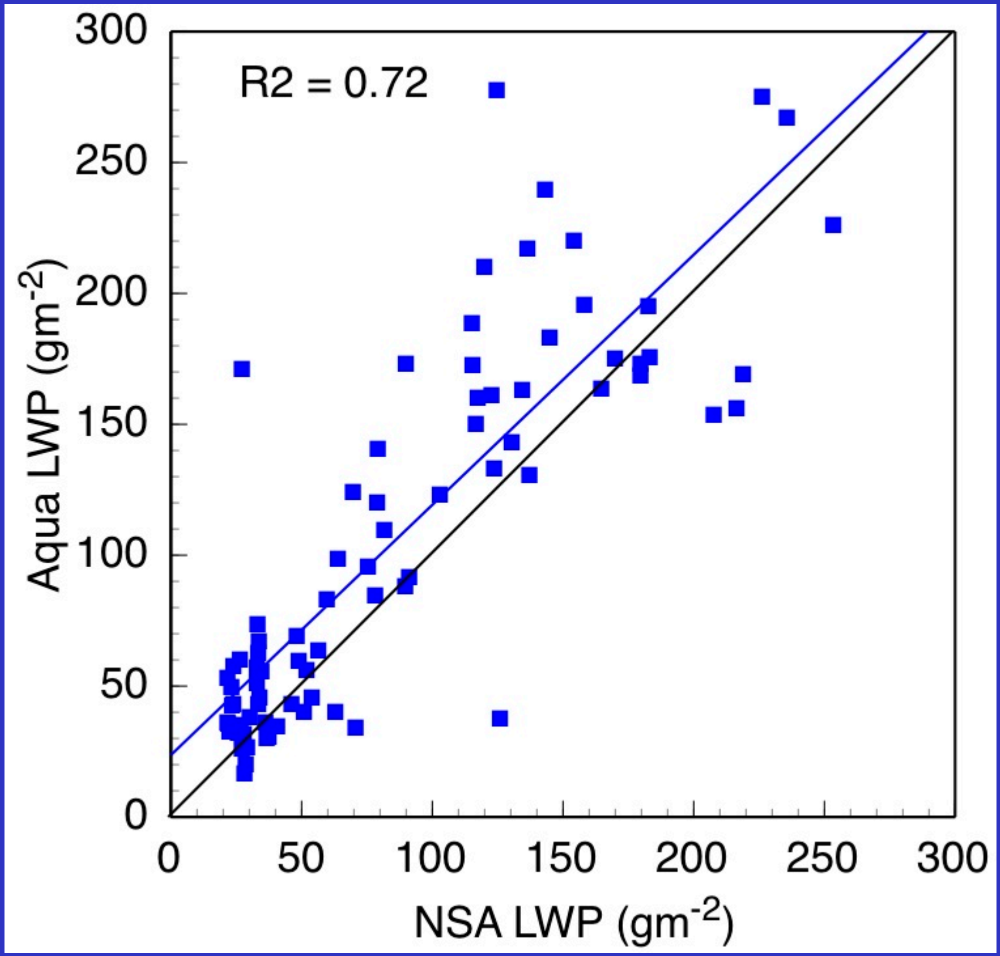
Aqua CERES-MODIS LWP vs ARM NSA LWP

- Reasonable correlation
  - offset?

- Bias: 25 $\pm$ 34 gm^{-2}

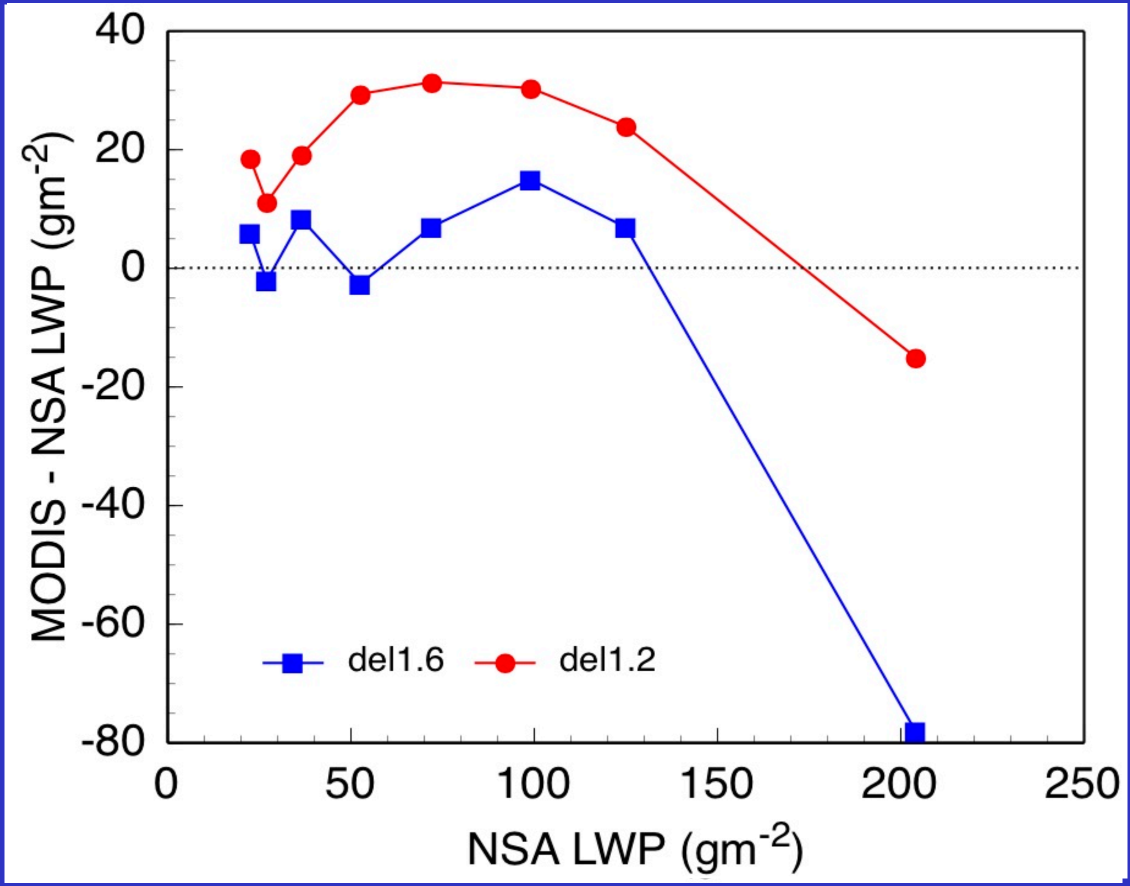
  27 $\pm$ 38 %

- COD does not compensate for Re overestimate like 1.6 µm retrieval

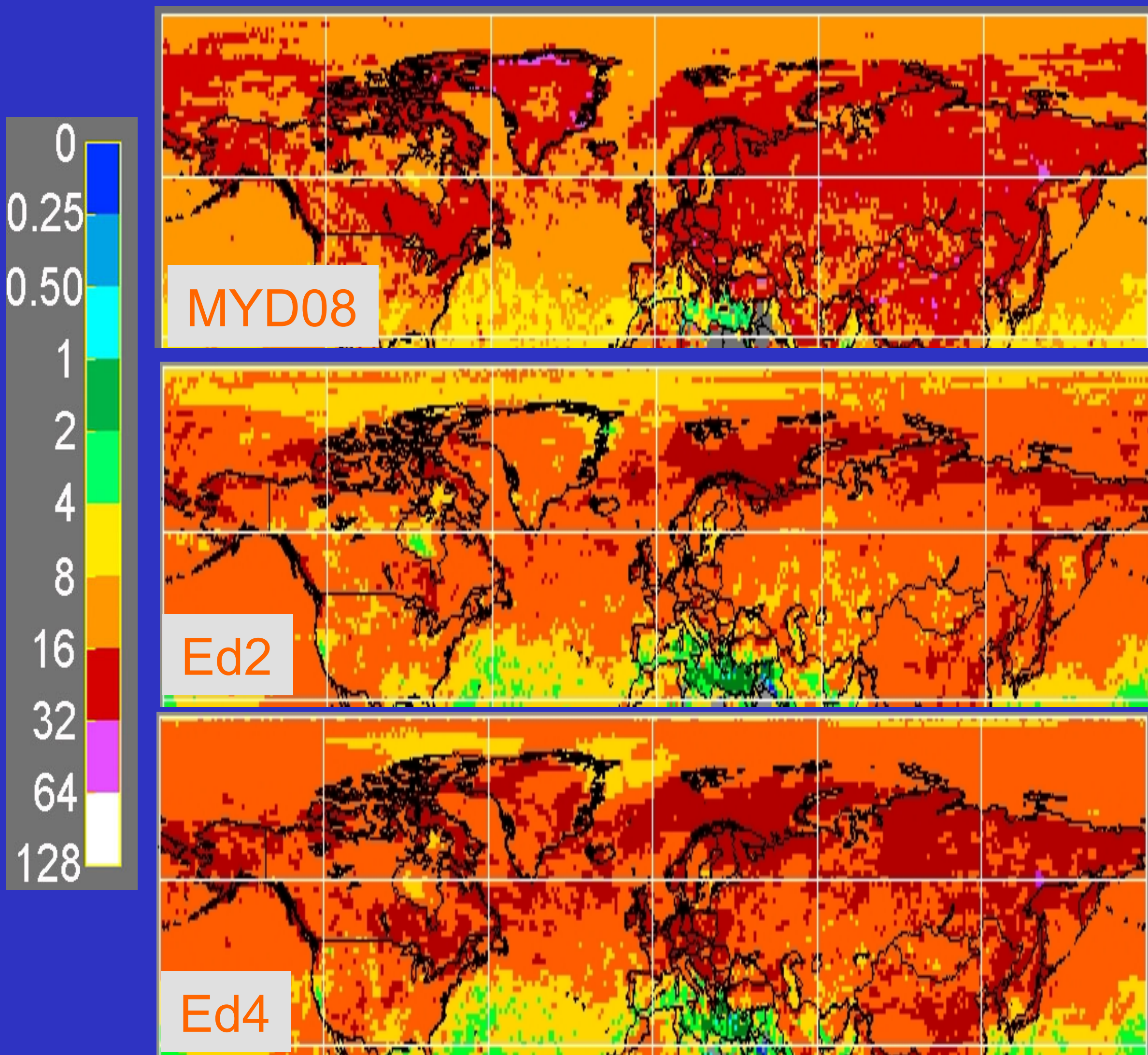


CERES-MODIS LWP - ARM NSA LWP, CF > 60%

- 1.6-µm LWP in good agreement for LWP < 150 gm^{-2}
  - *- underestimate for greater values*
- 1.2-µm overestimates LWP < 150 gm^{-2}
  - *- perhaps better for greater values*
  - *- parameterization of RTM need improving?*



Mean Liquid Cloud Optical Depth
Aqua/Terra MODIS, July 2008



- MYD08 C5 produced with 1.24 µm for polar COD by MODIS Sci Team
- CERES Ed2 used 1.6 µm
- CERES Ed4 used 1.2 µm

<u>75 – 90°N</u>

- MYD08 mean COD ~16
- Ed2 mean OD = 11.6
- Ed4 mean COD = 11.9
  - r_e = 13 µm
  - LWP = 90.6 gm^{-2}

Conclusions for Retrieval of Liquid Clouds over Snow

- 1.6/2.13-μm channels mostly equivalent, but limited to τ(liq) < 32
  - 1.6 μm agrees best with MWR LWP <150, up to τ = 16
  - 2.1 μm equivalent for water clouds, up to $\tau \sim 10$
  - not too sensitive to surface albedo variability, especially over ocean

- 0.62 & 0.86 μm channels very challenging *(Key et al., Devasthale et al.)*
  - extremely sensitive to surface albedo variability
  - clouds often darker than clear scenes
    - *difficult to model, need to know sfc albedo & BRDF accurately*

- 1.24-μm channel best for thick clouds *τ(liq) > 16*
  - sensitive to surface albedo variability
  - Re too high & COD too low, why?

- Potential of hybrid method
  - low τ = 0 -3: IR; medium τ = 3 -16: 1.6 μm; thick τ > 16: 1.24 μm
  - low τ = 0 -3: IR; medium τ = 3 - 8: 2.1 μm; thick τ > 8: 1.24 μm

Future

- Complete testing of all channels for ice and water
  - ice clouds may require a different set of clouds
- Examine sensitivity of Re retrievals to order of iteration and vertical profiles of R
  - examine uncertainties in surface Re & COD retrievals
- Limit matched data to snow over both ice and water
- Further study use of 0.65/0.87 µm bands for snow retrievals
  - only alternative for climatology before 2000 (i.e., AVHRR)
  - better representation of background albedo & BRDF
  - combine with IR retrieval of small-OD clouds
- Study use of hybrid methods for future analyses
  - VIIRS 0.65, 0.86, 1.2, 1.6, 2.2, 3.8, 11, 12, 13.4 µm